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Poultry litter and tillage influences on corn production and soil nutrients in a Kentucky silt loam soil

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Abstract

Broiler chicken (Gallus gallus) manure, a rich source of plant nutrients, is generated in large quantities in southeastern USA where many row crops, such as corn (Zea mays L.), are also extensively grown. However, the use of broiler manure as an economical alternative source of nutrients for corn production has not been extensively explored in this region. This study was conducted to examine the use of broiler litter as a source of nutrients for corn production, as influenced by tillage and litter rate, and any residual effects following application. In addition, the consequence of litter application to soil test nutrient levels, particularly P, Zn and Cu, was explored. The treatments consisted of two rates of broiler litter application, 11 and 22 Mg ha⁻¹ on a wet weight basis, and one rate of chemical fertilizer applied under no-till and conventional tillage systems. Treatments were replicated three times in a randomized complete block design. Corn was grown with broiler litter and inorganic fertilizer applied to the same plots each year from 1998 to 2001. In 2002 and 2003, corn was planted no-till, but only N fertilizer was applied in order to make use of other residual litter nutrients. Soil samples were taken yearly in the spring prior to litter application and 4 years after the cessation of litter application to evaluate the status of the residual nutrients in soil. Two years out of the 4-year experiment, broiler litter application produced significantly greater corn grain yield than equivalent chemical fertilizer application and produced similar grain yield in the other 2 years. Corn grain yield was significantly greater under no-till in 1999, but significantly greater under conventional-till in 2000, and no difference between the two tillage systems were observed in 1998 and 2001. With 4 years of litter application, Mehlich-3 P increased from an initial 18 mg kg⁻¹ to 156 mg kg⁻¹ with 11 Mg ha⁻¹ litter and to 257 mg kg⁻¹ with 22 Mg ha⁻¹ litter. For every 6 kg ha⁻¹ of P applied in poultry litter Mehlich-3 P was increased by 1 mg kg⁻¹. Modest increases in Mehlich-3 Cu and Zn did not result in phytotoxic levels. This study indicated that an optimum rate of broiler litter as a primary fertilizer at 11 Mg ha⁻¹ applied in 4 consecutive years on a silt loam soil produced corn grain yields similar to chemical fertilizer under both no-till and conventional tillage systems and kept soil test P, Cu and Zn levels below values considered to be harmful to surface water quality or the crop. © 2007 Elsevier B.V. All rights reserved.

Keywords: Broiler litter; Poultry manure; Corn; Tillage; Residual nutrients

1. Introduction

Broiler (chicken, *Gallus gallus domesticus*) litter (a combination of manure plus bedding materials) is

commonly applied to pasture and hay fields as a source

of plant nutrients. However, the use of broiler litter on row crops such as corn (*Zea Mays* L.) has not been as extensive (Burmester et al., 1991; Sistani et al., 2004). Sims (1986) and Ma et al. (1999) reported that application of poultry litter as a source of N and P increased forage and corn yield. Poultry litter applications improve soil quality compared to chemical

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fertilizers (Nyakatawa et al., 2001; Grandy et al., 2002). The USDA Natl. Agric. Stat. Serv. (2002) reported the production of more than 3 billion broiler chickens in 2001 generating 2.5 billion kg of litter. Therefore, considering the high cost of chemical fertilizer production, utilization of poultry litter as a source of plant nutrients becomes very practical. There are reports of greater crop yields with manure application compared to fertilizer use. Singh et al. (1996) reported wheat yield increased due to manure application compared to chemical fertilizers, and also observed significantly greater soil organic matter and extractable P in the manure-amended plots. Similarly, McAndrews et al. (2006) reported an increase of 0.2-0.5 Mg ha⁻¹ soybean grain yield in manure-treated plots compared to control (no manure applied) or urea-fertilized plots. Eghball et al. (2004) showed a positive effect of residual manure nutrients on the subsequent crop yield of corn.

Continued use of litter can accumulate P in surface soil horizons that can potentially enter runoff water. An increase of P in surface water that is P limited can cause the undesired effect of eutrophication. Predicting P movement of P from the field to surface water can be estimated using source and transport factors (Sharpley et al., 2003). A source factor includes the soil test P level. In Kentucky, when Mehlich-3 P level of 200 mg kg⁻¹ is exceeded, litter application is based on crop removal or a P index rating to evaluate the likelihood of P runoff (USDA-NRCS, 2001). It is important for growers to know how quickly soil test P levels will rise to the value of 200 mg kg⁻¹ with continued litter application and how quickly soil test P levels will decline with cessation of litter application if soil test P levels exceed 200 mg kg⁻¹.

Copper and Zn accumulation in soil increases with continued manure application (Brock et al., 2005). North Carolina has critical toxic levels to plants of 60 mg kg⁻¹ Mehlich-3 Cu and 120 mg kg⁻¹ Mehlich-3 Zn (Tucker et al., 2005). It is not known if continuous litter application would cause a problem with elevated Cu and Zn soil levels that may be phytotoxic.

There is abundant research on the advantage of notill cropping system in the literature (Lal and Van Doren, 1990; Sidhu and Duiker, 2006). However, problems have also been reported in no-till systems such as soil compaction, poor seedling emergence, and reduced yield (Raper et al., 2000; Schwab et al., 2002). In addition, questions arise on availability of plant nutrients in litter are when applied to the soil surface without incorporation (Grove, 1997). Application of poultry litter under no-till soil management concentrates P at the soil surface that can dissolve in runoff

water (Daverede et al., 2003; Kleinman and Sharpley, 2003).

The objective of this study was to investigate the use of broiler litter as a source of nutrients for corn production as influenced by tillage and litter rate and to evaluate changes in Mehlich-3 soil test nutrient levels for P, Cu, and Zn.

2. Materials and methods

This study was initiated in 1998 on a Zanesville silt loam soil (Fine-silty, mixed, mesic Typic Fragiudalf) with 0-2% slope in Princeton, Kentucky in Caldwell county. The treatments were arranged in a split-plot design with tillage being the main plots and nutrient application being the split plots. The tillage treatments consisted of no-till (NT) and conventional tillage (CT). Conventional tillage consisted of chisel plowing and disking the soil. The nutrient application treatments consisted of a control, which was fertilized only with chemical fertilizers, and two rates of broiler litter at 11 and 22 Mg ha⁻¹ on a wet weight basis. For the chemical fertilizer treatment, P and K were applied according to soil test results on samples taken every spring prior to planting using University of Kentucky fertilizer recommendations (University of Kentucky, 2006). The amount of fertilizer nitrogen applied was 169 kg N ha⁻¹ applied as ammonium nitrate. For CT. fertilizer or litter was applied and then incorporated with tillage, while for NT, treatments were surface applied on the plots. These methods of fertilizer and litter application are the practices that farmers normally use in the region.

A commonly used litter application rate for corn is 11 Mg ha⁻¹. With an average nitrogen content of 26.6 g (kg wet)⁻¹ in the litter (Table 1) and the estimation that about half of the nitrogen is available to the crop (Rasnake, 2002), the available nitrogen with 11 Mg ha⁻¹ of litter was 146 kg N ha⁻¹. This value was similar to the chemical fertilizer application of 169 kg N ha⁻¹. The nitrogen application rate recommended for corn using University of Kentucky recommendations is 157-196 kg ha⁻¹ (University of Kentucky, 2006). The litter rate of 22 Mg ha⁻¹ provided available nitrogen of 292 kg ha⁻¹. The 22 Mg ha⁻¹ litter rate evaluated effects of a high application rate used more as a disposal rate for the litter that would exacerbate potential problems with increased levels of P, Cu and Zn in the soil.

Corn was planted in plots consisting of four 0.75 m wide rows that were 15 m long in early May and harvested as grain in September by picking the two

Table 1 Nutrient and moisture analysis of litter applied each year

	Moisture (%)	N (g (kg wet) ⁻¹)	$P \\ (g (kg \\ wet)^{-1})^a$	$K (g (kg wet)^{-1})^a$	Ca (g (kg wet) ⁻¹) ^a	$Mg (g (kg wet)^{-1})^a$	Fe (g (kg wet) ⁻¹) ^a	$Cu (g (kg wet)^{-1})^a$	Zn $(g (kg wet)^{-1})^a$
1998	38	29.6	19.4	24.7	nd ^b	nd	nd	nd	nd
1999	38	29.5	12.4	19.6	nd	nd	nd	nd	nd
2000	26	20.0	22.3	18.7	31.5	7.0	12.4	0.83	0.45
2001	17	27.5	14.4	20.8	19.5	5.5	5.0	0.61	0.28

^a Concentration of nutrients expressed on a wet weight basis as applied in the field.

center rows for a harvest area of $1.5~\mathrm{m}\times 9~\mathrm{m}~(13.5~\mathrm{m}^2)$. The same treatments were applied on the same plots and corn was planted each year from 1998 to 2001. In 2002 and 2003, corn was planted using NT, but no broiler litter was applied. The entire experiment was fertilized only with nitrogen at 202 kg N ha⁻¹ each year using ammonium nitrate. In 2004 and 2005, corn was not planted and fertilizer was not applied. The plots were mowed periodically.

Initial soil samples were taken before litter or fertilizer application in spring of 1998 at 0–10, 10–30, 30-45, and 45-60 cm depths on NT plots and 0-15, 15-30, 30-45, and 45-60 cm depths on conventional-till plots. Soil pH and Mehlich-3 analysis of these soils are shown in Table 2. In the springs of 1999, 2000, and 2002, surface soil samples were taken at a depth of 0-10 cm for NT and 0–15 cm for conventional-till prior to applying the current year litter and fertilizer treatments. In spring of 2001, after 3 years of litter application, and in fall of 2005, 4 years after ceasing litter application, soil samples were taken at depths of 0-10, 10-30, 30-45, and 45-60 cm. Soil was dried at 38 °C, ground to pass a 2 mm screen and tested for pH using a glass electrode with a 1:1 soil:water ratio (Southern Cooperative Series Bulletin, 1983). Phosphorus, K, Ca, Mg, Zn, Fe, and Cu were analyzed following Mehlich-3 extraction (Donohue, 1992). For soils

sampled each spring from 1998 through 2002, soil was measured with a 2 cm³ scoop and results presented on a basis of mg kg⁻¹ which assumes the density of scooped soil was 1 g cm⁻³. For soil sampled in fall 2005, 2 g of soil was weighed for the extraction. For soils sampled the springs of 1999 and 2000, P in the Mehlich-3 extracts was determined via colorimetric analysis (Donohue, 1992) and the other analytes were determined with atomic absorption spectroscopy. For soils sampled in the springs of 2001 and 2002 and fall of 2005, all analytes were determined with inductively coupled plasma (ICP) spectrophotometry. Differences in P in Mehlich-3 extracts between colorimetric and ICP analysis were assumed to be negligible as observed for a large portion of Kentucky soils (Sikora et al., 2005).

The nutrient content of broiler litter was determined prior to application each year (Table 1). The manure was oven dried at 65 °C and ground to pass a 2 mm screen. Nitrogen was determined via combustion using LECO. The other nutrients were determined via digestion of the dried ash manure followed by analysis with inductively coupled plasma (ICP) spectrophotometry. Rainfall precipitation was monitored during the study and the cumulative monthly precipitation is reported in Fig. 1.

Analysis of variance was used to analyze the data using PROC GLM procedure of SAS (SAS, 1999).

Table 2 Initial soil pH and Mehlich-3 (M3) nutrient concentrations for NT and CT plots in spring 1998

Tillage	Soil depth (cm)	pН	$M3-K $ $(mg kg^{-1})$	$M3-Ca$ $(mg kg^{-1})$	M3-Mg (mg kg ⁻¹)	M3-P (mg kg ⁻¹)	$M3-Zn $ $(mg kg^{-1})$
NT	0–10	6.0	90	1570	160	24	1.2
NT	10-30	5.4	50	1190	100	2	0.2
NT	30-45	4.9	60	760	180	1	0.2
NT	45–60	4.6	80	510	310	1	1.0
CT	0–15	6.0	80	1480	90	13	0.5
CT	15-30	5.5	60	1350	130	2	0.2
CT	30-45	4.7	70	860	200	1	0.4
CT	45–60	4.6	70	590	270	3	1.0

b nd = not determined.

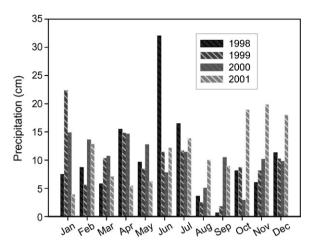


Fig. 1. Total monthly precipitation (cm) during the study from 1998 to 2001.

Analysis of variance showed significant differences among years and between year and treatment interaction, therefore data were analyzed and reported by year. There were no significant interactions between fertilizer source and tillage for any observations. Therefore, just the main treatment effects of fertilizer source and tillage are reported. Least significant differences (L.S.D.) were used to separate means at the 0.05 probability level.

3. Results

3.1. Grain yield

Corn grain yield was affected similarly by chemical fertilizer and broiler litter application as a nutrient source in 1998 and 2001 (Fig. 2). The 1998 yield was lower due to excessive rainfall (Fig. 1) causing a delay

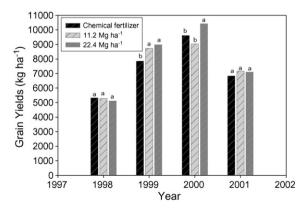


Fig. 2. Corn grain yield response to broiler chicken litter and N fertilizer from 1998 to 2001. Within each year, bars followed by the same letter are not significantly different according to L.S.D. at 0.05 probability level.

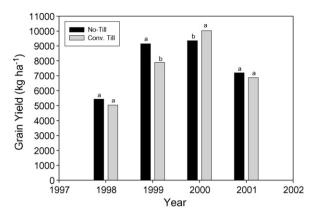


Fig. 3. Corn grain yield response to two tillage systems influenced by broiler chicken litter applicatin from 1998 to 2001. Within each year, bars followed by the same letter are not significantly different according to L.S.D. at 0.05 probability level.

in planting. No significant difference in corn grain yield was detected between rates of 11 and 22 Mg ha⁻¹ in 1998 and 2001. In 1999, yield from broiler litter application was significantly greater than chemical fertilizer treatment, however no significant yield increase was obtained from increasing the litter rate. In 2000, there was no significant difference in grain yield between chemical fertilizer treatment and the lower rate of broiler litter. However, significantly greater grain vield was obtained at a litter rate of 22 Mg ha⁻¹ (Fig. 2). In general, 2 years out of the 4year experiment (1999 and 2000), broiler litter application as a source of nutrient produced significantly greater corn grain yield than chemical fertilizer application, and produced similar grain yield in 1998 and 2001.

Fig. 3 shows corn grain yield was significantly greater under NT in 1999, but significantly greater under conventional-till in 2000, and no difference between the two tillage systems was observed in 1998 and 2001. There was no significant interaction between tillage and litter rate with regard to grain yield.

3.2. Soil nutrient status

Soil pH of plots receiving broiler litter increased significantly compared to chemical fertilizer treatment during the latter 3 years of litter application (Table 3). No soil pH increase was observed by increasing litter rate from 11 to 22 Mg ha⁻¹. Soil Mehlich-3 P and Zn were significantly greater for litter than chemical fertilizer treatments. Also, significant increases of P and Zn were measured by increasing broiler litter rate from 11 to 22 Mg ha⁻¹ (Table 3). Mehlich-3 extracted P

Table 3
Soil pH and Mehlich-3 (M3) nutrient concentrations (average of two tillage treatments) in surface soils sampled in springs of 1999, 2000, 2001, and 2002

Litter rate (Mg ha ⁻¹)	pН	$M3-K$ $(mg kg^{-1})$	M3-Ca (mg kg ⁻¹)	$M3-Mg$ $(mg kg^{-1})$	M3-P (mg kg ⁻¹)	$M3-Zn$ $(mg kg^{-1})$
1999						
0	6.0	100	1270	100	26b	0.9b
11	6.0	110	1250	110	39b	1.5b
22	6.1	140	1290	120	58a	2.7a
L.S.D. ^a	ns	ns	ns	ns	13	1.0
2000						
0	5.8b	110	920	80	23c	0.7c
11	6.0ab	170	1030	120	54b	2.9b
22	6.1a	260	1100	130	78a	4.6a
L.S.D. ^a	0.2	ns	ns	ns	9	1.2
2001						
0	5.7b	70c	1080b	80c	21c	0.8c
11	6.1a	170b	1290a	140b	116b	5.3b
22	6.2a	260a	1360a	190a	213a	9.7a
L.S.D. ^a	0.2	30	80	30	47	1.4
2002						
0	5.8b	120c	1320b	100c	24c	1.0c
11	6.3a	260b	1660a	190b	156b	7.1b
22	6.4a	370a	1720a	220a	257a	12.1a
L.S.D. ^a	0.2	40	160	20	57	4.0

^a Least significant difference (L.S.D.) values are presented at a 0.05 probability level. If the L.S.D. value was greater than the difference between means, ns denotes there was no significant difference. Means followed by different letters (a–c) within columns within a year are significantly different based on the L.S.D. value.

increased from an initial average concentration of 18 mg kg^{-1} in 1998 (Table 1) to 156 and 257 mg kg^{-1} in 2002 for the 11 and 22 Mg ha⁻¹ litter rates, respectively (Table 3). Mehlich-3 K, Ca, and Mg were greater with litter application compared to fertilizer application in the latter 2 years of litter application.

Table 4 shows the soil nutrient status under two tillage systems. There was no difference in Mehlich-3 K, Ca, and Mg between NT and CT. Mehlich-3 P was significantly greater with NT compared to CT in 2000 and 2001. Mehlich-3 Zn was significantly greater with NT in 2000, 2001, and 2002. The greater increase of P and Zn on the soil surface with NT is due to non-incorporation of litter into the soil as occurred with CT.

Detailed soil samples were taken by depth in spring of 2001 after 3 consecutive years of litter application (Table 5). Mehlich-3 P, Cu, Fe, Zn, K, Ca, and Mg became greater with litter application at 0–10 cm depths as observed with the comparison of 0 Mg ha⁻¹ litter with litter rates of 11 and 22 Mg ha⁻¹. There were modest increases at the 10–30 cm depth and no increases at depths greater than 30 cm. Averaged across tillage treatments, soil surface extractable nutrients ranged from 21 to 213 mg kg⁻¹ for P, from 1.0 to 10.5 mg kg⁻¹ for Cu, from 54 to 69 mg kg⁻¹ for Fe, and

from 0.8 to 9.7 mg kg $^{-1}$ for Zn when comparing the plots with chemical fertilizer treatment (0 Mg ha $^{-1}$ litter) with the 22 Mg ha $^{-1}$ litter application treatment.

Table 6 shows soil chemical analysis in fall of 2005, 4 years after the cessation of litter application in 2001. In 2002 and 2003, corn harvested for grain was planted on plots previously receiving broiler litter to assess residual nutrients. In 2004 and 2005, the plots were left fallow and mowed periodically. Soil surface P was reduced from 156 mg kg⁻¹ in spring of 2002 to 72 mg kg⁻¹ for the plots that received 11 Mg ha⁻¹ and from 257 mg kg⁻¹ in spring of 2002 to 162 mg kg⁻¹ for the 22 Mg ha⁻¹ rate (Tables 2 and 6). There was little change in Mehlich-3 Fe, Cu and Zn.

4. Discussion

4.1. Grain yield

Grain yield was greater with litter application compared to conventional fertilizer application in 1999 and 2000 (Fig. 2). Yield difference in 2000 was most likely due to nitrogen. The nitrogen application rate for the chemical fertilizer treatment was 169 kg ha⁻¹. Assuming half of the nitrogen in the

Table 4
Soil pH and Mehlich-3 (M3) nutrient concentrations of surface soil samples in spring of 1999, 2000, 2001, and 2002 for NT and CT. Data is averaged across the chemical fertilizer and two litter application rate treatments

Tillage	pН	$M3-K (mg kg^{-1})$	$M3$ -Ca (mg kg $^{-1}$)	$M3-Mg (mg kg^{-1})$	$M3-P (mg kg^{-1})$	$M3-Zn (mg kg^{-1})$
1999						
NT	6.1	100	1250	100	45	1.7
CT	6.0	130	1370	110	37	1.8
L.S.D. ^a	ns	ns	ns	ns	ns	ns
2000						
NT	6.0	190	1070	120	67	3.6
CT	5.9	170	970	110	36	1.8
L.S.D. ^a	ns	ns	ns	ns	8	1.0
2001						
NT	6.1	200	1540	170	177	5.3
CT	6.1	190	1440	160	114	3.2
L.S.D. ^a	ns	ns	ns	ns	43	1.1
2002						
NT	6.2	254	1670	180	167	8.1
CT	6.2	241	1470	160	124	5.4
L.S.D. ^a	ns	ns	ns	ns	ns	2.5

^a Least significant difference (L.S.D.) values are presented at a 0.05 probability level. If the L.S.D. value was greater than the difference between means, ns denotes there was no significant difference.

poultry litter was available to the plant (Rasnake, 2002), the N content of the litter (Table 1) can be used to estimate available N from the litter. In 2000, the N content of the litter was lower than in the other years with an estimated 110 and 220 kg ha⁻¹ available N supplied by 11 Mg ha⁻¹ and 22 Mg ha⁻¹ litter rates, respectively. The yields with 11 Mg ha⁻¹, chemical

fertilizer, and 22 Mg ha⁻¹ coincided with increased levels of available N at 110, 169 and 220 kg ha⁻¹, respectively. The increase in yield in 1999 with 11 Mg ha⁻¹ compared to 169 kg N ha⁻¹ as chemical fertilizer was unlikely due to N since the 11 Mg ha⁻¹ supplied an estimated 162 kg ha⁻¹ available N that year which was similar to the chemical fertilizer N treatment.

Table 5
Soil pH and Mehlich-3 (M3) nutrient concentrations in the spring of 2001 at various soil depths after three consecutive annual applications of chemical fertilizer (0 litter application) and two litter rates (11 and 22 Mg ha⁻¹)

Treatment (Mg ha ⁻¹)	pН	$K \pmod{kg^{-1}}$	Ca (mg kg ⁻¹)	Mg (mg kg ⁻¹)	P (mg kg ⁻¹)	Cu (mg kg ⁻¹)	Fe (mg kg ⁻¹)	Zn (mg kg ⁻¹)
0–10 cm								
0	5.7b	70c	1076b	76c	20.8c	1.0c	54c	0.8c
11	6.1a	173b	1292a	144ab	116.0b	6.7b	63b	5.3b
22	6.2a	258a	1361a	190a	213.0a	10.5a	69a	9.7a
10-30 cm								
0	5.5b	39c	902a	83a	3.7c	0.6c	36a	0.2c
11	5.7a	58b	962a	89a	8.8b	1.1b	38a	0.6b
22	5.7a	77a	975a	98a	14.3a	1.4a	39a	0.8a
30-45 cm								
0	4.9a	41b	559b	144ab	1.67b	0.4b	28a	0.2b
11	4.9a	50a	654a	151a	3.50ab	0.7a	31a	0.4a
22	4.9a	53a	665a	160a	4.92a	0.9a	30a	0.4a
45-60 cm								
0	4.8a	48b	372b	228a	1.67b	0.6b	29a	0.3b
11	4.8a	56ab	409ab	234a	2.92ab	0.8ab	29a	0.5ab
22	4.8a	60a	414a	235a	4.25a	1.0a	30a	0.5a

Data are averaged across tow tillage systems. Within each soil depth values followed by the same letters (a-c) in each column are not significantly different according to L.S.D. 0.05 level.

Table 6
Soil pH and Mehlich-3 (M3) nutrient concentrations in the fall of 2005 at various soil depths after 4 years of ceasing four consecutive annual applications of chemical fertilizer treatment (0 Mg ha⁻¹ litter) and two litter rates (11 and 22 Mg ha⁻¹)

Treatment (Mg ha ⁻¹)	pН	$K = (mg kg^{-1})$	Ca $(mg kg^{-1})$	Mg $(mg kg^{-1})$	$P \\ (mg kg^{-1})$	$Cu \\ (mg \ kg^{-1})$	$Fe (mg kg^{-1})$	Zn $(mg kg^{-1})$
0–10 cm								
0	5.3b	53c	1050c	80c	10c	0.9c	84b	0.9c
11	5.5ab	116b	1308b	136b	72b	6.6b	97a	4.8b
22	5.6a	156a	1510a	170a	162a	9.1a	103a	8.8a
10-30 cm								
0	5.1b	28c	869b	84b	0.9c	0.3c	66a	0.2c
11	5.3ab	47b	953ab	100ab	2.9b	0.7b	71a	0.3b
22	5.5a	71a	1010a	108a	6.4a	0.9a	70a	0.5a
30-45 cm								
0	4.5a	21b	484b	154a	0.09a	0.2b	66b	0.1a
11	4.6a	29a	548ab	167a	0.09a	0.2b	69ab	0.1a
22	4.6a	33a	610a	139a	0.15a	0.3a	76a	0.1a
45-60 cm								
0	4.3a	25a	256b	290a	0.03a	0.4a	84ab	0.4a
11	4.3a	29a	306ab	281a	0.06a	0.4a	80b	0.3a
22	4.3a	32a	347a	245a	0.09a	0.4a	89a	0.3a

Data are averaged across two tillage systems. Within each soil depth values followed by the same letters in each column are not significantly different according to L.S.D. 0.05 level.

The increased yield in 1999 may be due to N if the available N in the litter was greater than the assumed fraction of 50% of the total N. Another explanation for increased vield could be greater availability of the micronutrient Zn. The Mehlich-3 soil Zn level in the spring of 1999 was 0.7 mg kg⁻¹ (Table 3) in the chemical fertilizer treated soil. This Zn level, with Mehlich-3 P of 23 mg kg⁻¹ and soil pH of 5.9, is barely sufficient for corn (University of Kentucky, 2006). The Mehlich-3 soil Zn levels for litter rates of 11 and 22 Mg ha⁻¹ were higher (Table 3) and clearly sufficient for corn growth. Zinc from litter may also have played a role in addition to N in improving yield in 2000. Yields were lower in 1998 and 2001 and there were no differences amongst treatments (Fig. 2). The lack of yield differences in 1998 and 2001 indicates some factor other than N and Zn was limiting growth which did not allow the yield-improving benefits of these nutrients to be realized. The main growth limiting factor in 1998 was a late planting date that occurred due to excessive rainfall.

Grain yield was affected by tillage treatments in 1999 and 2000 but no affects were observed in 1998 and 2001 (Fig. 3). In 1999, NT yields were greater than conventional-till yields but the opposite was true in 2000. An explanation is not readily apparent. In 2000, the lower estimated available N supplied with litter could have resulted in enough loss of N

via volatilization in the no-till conditions that resulted in lower yields. In 1999, corn may have responded better with higher available N or P near the soil surface early in the growing season under NT conditions.

4.2. Soil nutrient status

A concern with litter application is the concomitant increase of P in soil that can potentially be released in runoff water and impair surface water quality. In Kentucky, when a Mehlich-3 soil P is greater than 200 mg kg⁻¹, steps are required to assess field factors associated with the risk of P runoff and to minimize further P accumulation in soil by applying only an amount of P that is removed in the harvested portion of the crop (USDA-NRCS, 2001). The Mehlich-3 soil P in the soil surface layer increased from an average of 18 mg kg⁻¹ (Table 2) at the beginning of the study to 124 and 167 mg kg $^{-1}$ in the conventional and NT plots (Table 4), respectively, in the spring of 2002 after 4 years of litter application. Considering just the 22 Mg ha⁻¹ litter plots, Mehlich-3 P was 217 and 296 mg kg⁻¹ in the CT and NT plots, respectively (data not shown). Mehlich-3 P in soil samples taking in spring of 2001 at the very surface of the soil at a depth of 0-5 cm were 234 and 444 mg kg $^{-1}$ for the CT and NT plots, respectively (data not shown). The higher Mehlich-3 P in the NT plots was due to litter being surface-applied and not incorporated into the soil. This practice concentrates nutrients on the soil surface which may increase the risk of P being released in runoff water as a source component in a risk analysis considering both source and transport (Kleinman and Sharpley, 2003). More attention needs to be given to the practice of litter application on NT systems and the potential risk to P runoff. The source of P released to runoff could be the litter itself shortly after application or higher P concentrations that occur in the surface soil. Perhaps tillage every 4–5 years could alleviate the latter situation by mixing highly concentrated soil P with lower soil depths.

The Mehlich-3 soil P in the soil surface layer increased from an average of 18 mg kg⁻¹ (Table 1) at the beginning of the study to 156 and 257 mg kg⁻¹ for the 11 and 22 Mg ha⁻¹ litter treatments, respectively, in 2002 after four seasons of litter application and corn growth (Table 3). Taking the P concentration in the litter applied (Table 1), the total application of P over 4 years were 752 and 1504 kg ha⁻¹, respectively, for 11 and 22 Mg ha⁻¹ litter rates. With the average grain yield (Fig. 3) of 7500 kg ha⁻¹ and assuming a P concentration in the grain as 3.2 g kg⁻¹ (Heckman et al., 2003), the total removal of P over 4 years was 96 kg ha⁻¹. The difference between application and removal was 656 and 1408 kg ha⁻¹ for 11 and 22 Mg ha⁻¹ litter rates, respectively. Considering the quantity of P added to soil from the litter and the change in Mehlich-3 soil test P, it took 4.8 and 5.9 kg ha⁻¹ of P added to the soil in 11 and 22 Mg ha⁻¹ litter application rates, respectively, to increase Mehlich-3 soil test P by 1 mg kg⁻¹. These values are similar to results from a laboratory incubation study where 2.9-7.8 kg ha⁻¹ inorganic P increased Mehlich-3 soil test P by 1 mg kg⁻¹ depending on the initial Mehlich-3 values ranging from 62 to 15 mg kg⁻¹ (Thom and Dollarhide, 2002). The lower the Mehlich-3 value of soil in the laboratory incubation. a greater amount of P was required to raise Mehlich-3 by 1 mg kg^{-1} .

Soil test P values using Bray extractant are about 20% less than Mehlich-3 soil test P. The values of inorganic P required to raise Bray-P by 1 mg kg⁻¹ have been observed to be similar to the amount of poultry litter P required to increase Mehlich-3 P by 1 mg kg⁻¹. Peck et al. (1971) found 2.2–11.2 kg ha⁻¹ of inorganic P was required to increase Bray-P by 1 mg kg⁻¹ in laboratory incubations of Mollisols and Alfisols. In field studies with corn production and not accounting for P removal with the crop, they found 8.9 kg ha⁻¹ of fertilizer P was required to increase Bray-P by

1 mg kg⁻¹. Griffin and Hanna (1967) found 1.6–4.2 kg ha⁻¹ of inorganic P increased Bray-P by 1 mg kg⁻¹ in laboratory incubations of New Jersey soils. Values of 4.8 and 5.9 kg ha⁻¹ of poultry litter P required to increase Mehlich-3 P by 1 mg kg⁻¹ in the current study were determined by accounting for P removed in the corn grain. By not accounting for P removal by the crop, 5.4 and 6.3 kg ha⁻¹ of P with 11 and 22 Mg ha⁻¹ litter would be required to increase Mehlich-3 P by 1 mg kg⁻¹. The rounded average of the two P applications rates is 6 kg ha⁻¹ and is a value that can be used to assess how many years of litter application would result in reaching the 200 mg kg⁻¹ Mehlich-3 P limit which is an indicator of potential problems with surface water quality impairment in Kentucky.

An equally important parameter to assess the issue of water quality and P in soil is the rate of decrease in Mehlich-3 soil P upon the cessation of litter application. After ceasing litter application, the experimental plots were not fertilized. For 2 years, corn for grain was grown under NT conditions. For another 2 years, the plots were left fallow and mowed periodically. After these 4 years, the Mehlich-3 soil test P decreased from 156 to 72 mg kg⁻¹ for the 11 Mg ha⁻¹ litter rate and from 257 to 162 mg kg⁻¹ for the 22 Mg ha^{-1} litter rates (Tables 3 and 6). The decline in Mehlich-3 P was slower than the buildup. The average rate of increase in Mehlich-3 P during 4 years of litter applications was 34 and 60 mg kg⁻¹ year⁻¹ for 11 and 22 Mg ha⁻¹ litter rates. The average decline in Mehlich-3 P after 4 years was 22 mg kg⁻¹ year⁻¹ for both litter rates. The decline in Mehlich-3 P could have been due to either P removal in the harvested crop or fixation to more recalcitrant forms in the soil.

There is some concern that continuous litter application will elevate Cu and Zn in soil to levels harmful to plants or animals foraging on the plants (Warman and Cooper, 2000; Mantovi et al., 2003). The total Cu and Zn concentrations in Zanesville soil where this field study was conducted are 29 and 26 mg kg⁻¹, respectively, in the surface horizon (Karathanasis and Seta, 1993). Only about 4% of this amount is extracted by Mehlich-3 as shown by the values for the 0-10 cm depth in the chemical fertilizer treatment (Table 5). Mehlich-3 extracted a much lower percentage of total Fe which is 23,700 mg kg⁻¹ in the Zanesville soil (Karathanasis and Seta, 1993). The affect of litter application can be evaluated by comparing the chemical fertilizer and litter plots in Table 5 which show Mehlich-3 extractable nutrients after 3 years of litter application. Litter application increased Mehlich-3 Fe to 69.0 and modestly increased Mehlich-3 Cu and Zn to levels of 10.5 and 9.7 mg kg⁻¹, respectively, in the high litter rate of 22 Mg ha⁻¹. These levels were still well below critical toxic levels recommended for North Carolina soils which are 60 mg kg⁻¹ for Cu and 120 mg kg⁻¹ for Zn. Longer term application of litter may cause Cu and Zn levels to approach closer to these critical phytotoxic levels.

The increase in Mehlich-3 Cu and Zn that occurred with litter application (Table 5) did not decline after 4 years of ceasing litter application as occurred with P (Table 6). Mehlich-3 P declines were most likely due to P removal in corn grain harvested in 2 of the 4 years after litter application. Copper and Zn concentrations are much lower in corn grain (Heckman et al., 2003) indicating limited removal of the metals from the field under corn grain production.

References

- Brock, E., Ketterings, Q.M., McBride, M., 2005. Copper and zinc accumulation in manured soils. What's cropping up? Newsletter 15 (5), 5–6.
- Burmester, C.H., Wood, C.W., Mitchell, C.C., 1991. Broiler litter promising as a nitrogen source for cotton. Highlights Agric. Res. 38 (2), 3–4.
- Daverede, I.C., Hoeft, R.G., Nafziger, E.D., Bullock, D.G., Warren, J.J., Gonzini, L.C., 2003. Phosphorus runoff: Effect of tillage and soil phosphorus levels. Environ. Qual. 32, 1436–1444.
- Donohue, S.J., 1992. Soil and media diagnostic procedures for the Southern region of the United States. Virginia Agricultural Experiment Station, College of Agriculture and Life Sciences, Virginia Polytechnic Institute & State University. Southern Cooperative Series Bulletin No. 374.
- Eghball, B., Ginting, D., Gilley, J.E., 2004. Residual effects of manure and compost application on corn production and soil properties. Agorn. J. 96, 442–447.
- Grandy, A.S., Porter, G.A., Erich, M.S., 2002. Organic amendment and rotation crop effects on the recovery of soil organic matter and aggregation in potato cropping systems. Soil Sci. Soc. Am. J. 66, 1311–1319.
- Griffin, G.F., Hanna, W.J., 1967. Phosphorus fixation and profitable fertilization: 1. Fixation in New Jersey soils. Soil Sci. 103, 202– 208
- Grove, J.H., 1997. Establishing the value of the phosphorus and potassium contained in poultry litter for a no-till corn an soybean rotation. In: Gallaher, R.N., McSorley, R. (Eds.), Proc. 20th Ann. Southern Conserv. Till. Conf. for Sustainable Agriculture, Gainesville, FL, 24–26 June, pp. 169–174.
- Heckman, J.R., Sims, J.R., Beegle, D.B., Coale, F.J., Herbert, S.J., Bruulsema, T.W., Bamka, W.J., 2003. Nutrient removal by corn grain harvest. Agron. J. 95, 587–591.
- Karathanasis, A.D., Seta, A.K., 1993. Background Levels of Heavy Metals in Some Kentucky Soils. Bulletin 727. University of Kentucky, College of Agriculture, Agriculture Experiment Station, Lexington, KY.

- Kleinman, P.J.A., Sharpley, A.N., 2003. Effect of broadcast manure on runoff phosphorus concentrations over successive rainfall events. J. Environ. Qual. 32, 1072–1081.
- Lal, R., Van Doren, D.M., 1990. Influence of 25 years of continuous corn production by three tillage methods on water infiltration for two soils in Ohio. Soil Tillage Res. 16, 71–84.
- Ma, B.L., Dwyer, L.M., Gregorich, E.G., 1999. Soil nitrogen amendment effects on nitrogen uptake and grain yield of maize. Agron. J. 91, 650–656.
- Mantovi, P., Bonazzi, G., Maestri, E., Marmiroli, N., 2003. Accumulation of copper and zinc from liquid manure in agricultural soils and crop plants. Plant Soil 250, 249–257.
- McAndrews, G.M., Liebman, M., Cambardella, C.A., Richard, T.L., 2006. Residual effects of composted and fresh solid swine manure on soybean growth and yield. Agron. J. 98, 873–882.
- Nyakatawa, E.Z., Reddy, K.C., Sistani, K.R., 2001. Tillage, cover cropping, and poultry litter effects on selected soil chemical properties. Soil Tillage Res. 58, 69–79.
- Peck, T.R., Kurtz, L.T., Tandon, H.L.S., 1971. Changes in Bray P-1 soil phosphorus test values resulting from applications of phosphorus fertilizer. Soil Sci. Soc. Am. Proc. 35, 595–597.
- Raper, R.L., Reeves, D.W., Burmester, C.H., Schwab, E.B., 2000.
 Tillage depth, tillage timing, and cover crop effects on cotton yield, soil strength, and energy requirements. Appl. Eng. Agric. 16
 (4), 379–385.
- Rasnake, M., 2002. The Agronomics of Manure use for Crop Production. AGR-165. University of Kentucky, College of Agriculture, Cooperative Extension Service, Lexington, KY.
- SAS Institute, 1999. SAS/STAT User's Guide. Version 8. SAS Inst., Cary, NC.
- Schwab, E.B., Reeves, D.W., Burmester, C.H., Raper, R.L., 2002. Conservation tillage systems for cotton in the Tennessee Valley. Soil Sci. Soc. Am. J. 66, 569–577.
- Sharpley, A.N., Weld, J.L., Beegle, D.B., Kleinman, P.J.A., Gburek, W.J., Moore Jr., P.A., Mullins, G., 2003. Development of phosphorus indices for nutrient management planning strategies in the United States. J. Soil Water Cons. 58, 137–152.
- Sidhu, D., Duiker, S.W., 2006. Soil compaction in conservation tillage: Crop Impacts. Agron. J. 98, 1257–1264.
- Sikora, F.J., Howe, P.S., Hill, L.E., Reid, D.C., Harover, D.E., 2005. Comparison of colorimetric and ICP determination of phosphorus in Mehlich3 Soil Extracts. Comm. Soil Sci. Plant Anal. 36, 875– 887.
- Sims, J.T., 1986. Nitrogen transformation in a poultry litter amended soil: Temperature and moisture effects. J. Environ. Qual. 15, 59–63.
- Singh, B., Singh, Y., Maskina, M.S., Meek, O.P., 1996. The value of poultry manure for wetland rice grown in rotation with wheat. Nutr. Cycl. Agroecosyst. 47, 243–250.
- Sistani, K.R., Rowe, D.E., Johnson, J., Tewolde, H., 2004. Supplemental nitrogen effect on broiler-litter-fertilized cotton. Agron. J. 96, 806–811.
- Southern Cooperative Series Bulletin, 1983. Reference soil test methods for the Southern Region of the United States. The University of Georgia, College of Agriculture Experiment Station. Southern Cooperative Series Bulletin No. 289.
- Thom, W., Dollarhide, J., 2002. Phosphorus Soil Test Changes Following the Addition of Phosphorus Fertilizer to 16 Kentucky Soils. Agronomy Notes 34(2) University of Kentucky, College of Agriculture, Cooperative Extension Service, Lexington, KY.
- Tucker, M.R., Hardy, D.H., Stokes, 2005. Heavy metals in North Carolina soils. Occurrence and significance. N.C. Department of Agriculture and Consumer Services. www.ncagr.com/agronomi.

- University of Kentucky, 2006. 2006–2007 lime and nutrient recommendations. AGR-1. University of Kentucky, College of Agriculture, Cooperative Extension Service, Lexington, KY.
- USDA National Agricultural Statistics Service, 2002. Broiler production by state [Online]. Available at www.usda.gov/nass/aggraphs/brlmap.htm. USDA-NASS, Washington, DC.
- USDA-NRCS, 2001. Conservation Practice Standard: Nutrient Management Code 590. U.S. Department of Agriculture–Natural Resources Conservation Service, Lexington, KY.
- Warman, P.R., Cooper, J.M., 2000. Fertilization of a mixed forage crop with fresh and composted chicken manure and NPK fertilizer: Effects on soil and tissue Ca, Mg, S, B, Cu, Fe, Mn and Zn. Can. J. Soil Sci. 80, 345–352.